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Citation for published version:
Grobovsek, J 2018, 'Development accounting with intermediate goods', *B.E. Journal of Macroeconomics*, vol. 18, no. 1, 20160223, pp. 1-27. https://doi.org/10.1515/bejm-2016-0223

Digital Object Identifier (DOI):
10.1515/bejm-2016-0223

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
B.E. Journal of Macroeconomics

DEVELOPMENT ACCOUNTING WITH INTERMEDIATE GOODS

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May 2017

Abstract. I use a simple development accounting framework that distinguishes between goods and service industries on the one hand, and final and intermediate output on the other hand, to document the following facts. First, poorer countries are particularly inefficient in the production of intermediate relative to final output. Second, they are not necessarily inefficient in goods relative to service industries. Third, they present low measured labor productivity in goods industries because these are intensive intermediate users, and because their intermediate TFP is relatively low. Fourth, the elasticity of aggregate GDP with respect to sector-neutral TFP is large.

I would like to thank Juan Carlos Conesa, Vasco Carvalho, Tim Kehoe, Nezih Guner, Albert Marcet, Sevi Rodríguez Mora, Omar Licandro, and Francesco Caselli for helpful comments. I would also like to thank participants at the XV Workshop on Dynamic Macroeconomics at Vigo, the 2011 ENTER Jamboree in Tilburg, the 2011 EEA meetings in Oslo, and workshop participants at the Universitat Autònoma de Barcelona, the University of Minnesota, and the University of Edinburgh. An earlier version of this paper won the FEEM award for the best three papers by young economists at the 2011 EEA meetings in Oslo. All errors are mine. Please send comments to jan.grobovsek@ed.ac.uk.

JEL codes: O10, O41, O47.

Key words: Development Accounting, Productivity, Intermediate Goods, TFP.

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1. Introduction

In a typical economy, the value of intermediate consumption relative to gross output is roughly one half. Despite their quantitative importance as production factors, intermediate goods have received relatively little attention in the literature on development accounting. To motivate why it is reasonable to account for intermediates explicitly, I document the following stylized facts.

(1) The relative price of intermediate vis-à-vis final output declines along development. Poorer countries need to cope with relatively expensive intermediate production factors which, to the best of my knowledge, is a novel finding. (2) Across countries the price ratio between intermediate services and goods is positively correlated with GDP per hour. This mimics the well-known analogous stylized fact for the price ratio between final goods and services. (3) Both goods and service industries exhibit remarkably constant intermediate consumption shares across countries, with goods having a higher intermediate share than services. This is not a new finding *per se*, but it has remained largely unexploited in development accounting, with the notable exceptions of Moro (2015) and Duarte and Restuccia (2015). (4) In addition, I identify that the composition of intermediate expenditure is *not* constant across countries. It shifts towards intermediate services as countries grow richer.

I construct a development accounting model that accommodates the above evidence. It features the simplest possible closed-economy framework based on four sectors characterized each by industry (goods or services) and production stage (intermediate or final output). Intermediate production is endogenous while the other production factor, labor, is in fixed supply. Goods differ from service industries in intermediate intensity as well as efficiency (TFP). Intermediate versus final producers, in contrast, operate identical production functions except for variations in TFP.

The model is kept deliberately simple to uncover broad cross-country TFP trends along the two proposed dichotomies, and to analyze sectoral interdependencies. The distinction between goods and services is standard. Why, though, should relative production stage TFP differ across countries? It can broadly capture two phenomena. The first one is that production stages differ in the composition of specific sub-industries. For example, although car and steel industries cater to both final and intermediate use, they do so in different proportions. TFP in the final goods sector will strongly reflect the efficiency of car assembly while intermediate good TFP will more strongly capture the efficiency of producing steel. Second, identical physical goods and services may well be produced with varying degrees of efficiency depending on their destination, for instance due to market structure or contractual arrangements. These differences are measured when comparing intermediate and final price deflators across countries. As such, the paper offers a simple conceptual contribution in the form of a diagnostic tool. Its shortcoming, admittedly, is that it does not allow to pinpoint precisely which specific sub-industries, frictions or policies are responsible for low TFP.

I evaluate the model on two distinct data sources featuring internationally comparable industry prices. The first is the Groningen Growth and Development Centre Productivity Level dataset for the base year 1997 (GGDC henceforth). The second is the World-Input Database for the year 2005 (WIOD henceforth). While both datasets are consistent on the previously mentioned stylized facts, they are also sufficiently distinct along several dimensions to require separate quantifications.[1]

The first contribution of the paper is to determine which sectors are particularly inefficient in poorer economies. This can be summarized by the average TFP ratio between the poorest and richest quintiles of countries. Using GGDC (WIOD) it is 0.73 (0.55) in final goods, 0.69 (0.43) in final services, 0.44 (0.46) in intermediate goods, and 0.46 (0.34) in intermediate services. To put these results into perspective, I compute the following elasticities for the two proposed dichotomies. First, a percent increase in final sector TFP is associated with a 1.47 (1.24) percent increase in intermediate sector TFP in the GGDC (WIOD) sample. I conclude that poorer countries feature substantially lower TFP levels in intermediate relative to final output. Second, a percent increase in the goods sector TFP is associated with a 0.84 (1.35) percent increase in service sector TFP in the GGDC (WIOD) sample. I conclude that the comparison across industries is less clear-cut and that it depends on the sample. Contrary to expectations, poorer economies *do not* necessarily have low TFP in goods relative to service industries.

The second contribution is to use the quantified model to determine country-specific responses to TFP growth, and in particular to aggregate sector-neutral TFP growth. The focus is on two moments that are of special interest to development accounting. The first is *measured* labor productivity of final goods relative to services. Its elasticity to aggregate TFP in the GGDC (WIOD) sample ranges from 0.46 (0.72) in the poorest quintile of countries to 0.45 (0.69) in the richest quintile. In both samples these elasticities are large

[1] As will become clear shortly, the WIOD dataset includes a larger set of countries spanning a wider range of development levels. Also, because of differences in the definition of intermediate inputs, the intermediate share in the GGDC is substantially smaller.

and positive. Put differently, a rising tide does not lift all boats equally. Rather, goods industries benefit more strongly from sector-neutral TFP gains than services. The second moment of interest is GDP. Its elasticity to aggregate TFP in the GGDC (WIOD) sample ranges from 1.81 (2.23) in the poorest quintile of countries to 1.80 (2.13) in the richest quintile. I conclude that the inclusion of intermediate inputs creates a substantial GDP multiplier with respect to TFP growth.

Theoretically, an increase in aggregate TFP lowers all intermediate input prices relative to the price of labor, which is in fixed supply. Goods industries benefit disproportionately because their production is intensive in intermediate consumption. As a result, measured labor productivity of goods relative to services increases. It explains why poor countries present relatively expensive goods without having especially low TFP in those industries. Moreover, this non-neutral response diminishes as economies develop. In rich countries the composition of intermediate consumption is tilted more heavily towards intermediate services. These generate a weaker transmission of TFP gains than intermediate goods because they are themselves less intensive in intermediate consumption. Consequently, the elasticity of GDP to aggregate TFP is weaker in richer countries. This sheds new light on the proverbial 'cost disease' of Baumol (1967). It occurs because service industries have a lower intermediate intensity than goods, while at the same time becoming increasingly important intermediate suppliers as economies grow more efficient.

Moro (2015) similarly exploits differences in intermediate intensity between manufacturing and services to show that TFP growth in poorer countries results in larger GDP multipliers due to structural transformation. The present paper differs in its applied part by allowing for variations in the nominal input composition and by distinguishing between intermediate and final TFP. I also show that differences in intermediate intensity imply that measured relative sectoral productivity is biased towards goods industries as economies develop. In addition, the focus is different. Here I quantify TFP levels while Moro (2015) centers on the relationship between structural transformation and *growth* rates, both in terms of trend and volatility.

More generally, this paper is closely related to the literature on sectoral development accounting, i.e. the quest for the 'problem sectors' in poorer economies. Based on final expenditure price data, Herrendorf and Valentinyi (2012) compute that low-income countries are particularly unproductive in goods as compared to service industries. This is in line with evidence from Bernard and Jones (1996a) who show that during the 1970's and 1980's OECD countries have experienced productivity convergence in services, but not in manufacturing.[2] It also underlies the Balassa-Samuelson hypothesis according to which services are internationally less tradable. Duarte and Restuccia (2010), in contrast, circumvent the problem of unreliable relative price measurements across countries by inferring cross-country sectoral TFP from a structural model based on employment shares. They find that rich compared to poor countries have higher productivity levels in the production of agricultural goods and *services*, but a less pronounced productivity advantage in manufacturing. The present paper is a step towards reconciling these outcomes by emphasising that input-output patterns and intermediate costs may well lead to high relative final expenditure goods prices in poor countries despite their relatively high TFP levels in goods versus services. This is precisely in line with recent findings from Duarte and Restuccia (2015) who identify substantially smaller cross-country TFP gaps between manufacturing and a subset of services when input-output relations are explicitly accounted for.

Sectoral growth accounting analyses across countries have been hampered by the availability of internationally comparable industry price data. Final expenditure data are only an imperfect substitute, as cautioned by Heston and Summers (1996). Exceptions that do use sectoral industry prices and explicitly account for intermediate inputs include Jorgenson, Kuroda and Nishimizu (1987), Lee and Tang (2000), and van Ark and Pilat (1993) for specific country comparisons, as well as Inklaar and Timmer (2007) for a larger set of countries. In these studies, intermediates inputs are exogenously retrieved from the data rather than a general equilibrium outcome. The advantage of treating intermediate inputs as endogenous is that it delivers total rather than partial TFP multipliers.[3] In fact, the approach here is very similar in spirit to the work of Hsieh and Klenow (2007) on physical capital. They stress that nominal investment rates as measured in local prices are comparable across countries, while real investment rates are substantially lower in poorer countries. Our story is analogous to the extent that the nominal intermediate share across

[2]Related literature on cross-country convergence at the aggregate economy level includes Baumol (1986), Barro and Sala-i Martín (1992), Mankiw, Romer and Weil (1992) and Bernard and Jones (1996b). Articles on sectoral convergence using producer prices include Sørensen and Schjerning (2008), Inklaar and Timmer (2009), and Levchenko and Zhang (2016).

[3]This point is theoretically made in Melvin (1969) and Hulten (1978).

countries is shown to be stable while the real intensity is lower in poorer countries due to relatively high intermediate prices.[4]

A number of recent articles single out input-output relationships to explain cross-country aggregate productivity differences. Jones (2011) demonstrates how generic wedges that disperse the marginal productivity of intermediates lower aggregate productivity depending on intermediate intensity and complementarity. Building on a similar framework, Bartelme and Gorodnichenko (2015) find evidence that aggregate productivity across time and space is positively associated with a measure of input-output linkages based on (nominal) intermediate intensity.[5] Their detailed exercise suggests that there are modest but robust gains from increasing the intermediate intensity, and that distortions in intermediate input trade indeed decrease the strength of linkages. The present paper is complementary to these findings. The nominal intermediate intensities for any industry are taken as given, but the composition of intermediates is allowed to vary across countries in response to price changes. The difference is that in the present setup direct price measurements are used to identify sectoral TFP differences rather than distortions rationalized by generic wedges.[6] Another closely related paper is Fadinger, Ghiglino and Teteryatnikova (2016). Their focus is on the interaction between country-specific IO linkage structures and sectoral productivities. Their finding is that poorer countries feature a more extreme distribution of sectoral IO multipliers. They also find that imposing the IO structure of rich countries on poorer ones would lower their aggregate productivity because it would increase the weight of currently isolated sectors that have relatively low productivity.[7]

A number of contributions establish explicit micro foundations for input-output trade and its interplay with aggregate productivity. On the one hand, a higher degree of intermediate linkages may simply reflect the adoption of industrialization techniques that depend themselves on the level of aggregate income (Ciccone 2002). Alternatively, stronger linkages may depend on institutions and markets. Incompleteness of markets and relationship-specificity, for instance, can imply significantly higher input prices and lower outsourcing in the presence of weak contract enforcement (Acemoglu, Antràs and Helpman 2007,

[4]Some papers relate intermediate production directly to the relative cost of physical capital (Ngai and Samaniego 2009, Armenter and Lahiri 2012).

[5]Earlier evidence on such a relationship is found in Chenery, Robinson and Syrquin (1986).

[6]A number of papers study the impact on aggregate productivity of distortions in specific inputs markets (Restuccia, Yang and Zhu 2008, Adamopoulos 2011, Gollin and Rogerson 2014).

[7]For endogenous intermediate input network formation see Oberfield (2017) and Carvalho and Voigtländer (2015).

Boehm 2016). In addition, other institutional distortions may be responsible for the high price of intermediates in poorer countries. Examples are weak competitive pressures that disproportionately affect intermediate sectors (Amiti and Konings 2007) and international trade frictions that limit the transfer of technology embedded in intermediates (Kasahara and Rodrigue 2008, Goldberg, Khandelwal, Pavcnik and Topalova 2010, Halpern, Koren and Szeidl 2015).

The organization of the paper is as follows. Section 2 presents the empirical evidence. Section 3 proposes the model environment. The theoretical results of the model are summarized in Section 4. Section 5 presents the empirical findings. Section 7 concludes.

2. Empirical motivation

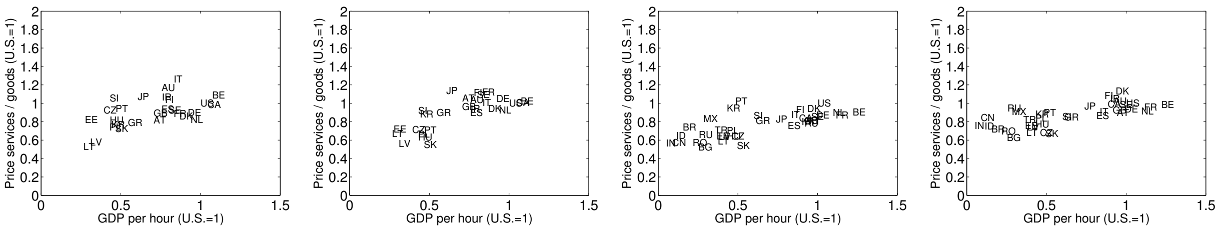
2.1. *Data*

The empirical motivation and all further quantifications are derived from two distinct data sources. The first is the Groningen Growth and Development Centre Productivity Level dataset for the base year 1997. It consists of a sample of 30 upper-middle and high income countries, and contains information on internationally comparable two-digit industry deflators. Importantly, it also contains price deflators for intermediate expenditures on goods (energy and materials) and services. I use these for the construction of relative prices of intermediate versus final goods and services. The second data source is the World-Input Database complemented by the GGDC Productivity Level Database for the year 2005. These data are more recent and have the added advantage of featuring a larger number of 40 countries, including several important lower-middle and upper-middle income economies. While they also provide internationally comparable industry deflators, they do not offer information on real intermediate expenditure. Here I choose an indirect approach to construct relative intermediate versus final prices by weighing two-digit industries in terms of their prominence in intermediate input supply. Furthermore, the two datasets differ in the definition of intermediate inputs. Contrary to standard input-output tables such as the WIOD, the GGDC dataset uses a more narrow definition of intermediate inputs by netting out intra-industry deliveries at the lowest level of aggregation (29 industries).[8] The construction of all the following series is summarized in the Appendix.

[8]For details see Inklaar and Timmer (2008), p 22. For additional discussion see O'Mahony and Timmer (2009).

2.2. *Relative prices*

Let p_{gf} and p_{sf} (p_{gm} and p_{sm}) denote the respective price of final (intermediate) goods and services. One well-known stylized feature from the comparison of final expenditure items across countries is that the relative price of services to goods correlates positively with GDP per hour. That is mirrored in relative industry deflators, as shown in Figure (1) where the first and third panels depict the relative price of goods versus service industries catering to final use in the GGDC and WIOD samples, respectively.[9] What is novel is that the relative price of *intermediate* goods to services follows an analogous pattern, as depicted in panels two and four of Figure (1). These two facts invite to the conclusion that in poorer countries both final and intermediate consumers face relatively expensive goods as opposed to services, i.e. $(p_{gf}/p_{sf})^{poor} > (p_{gf}/p_{sf})^{rich}$ and $(p_{gm}/p_{sm})^{poor} > (p_{gm}/p_{sm})^{rich}$. Put differently, poorer countries appear to have a particular productivity problem in goods relative to service industries.[10]



(A) Final, GGDC (B) Interm., GGDC (C) Final, WIOD (D) Interm., WIOD

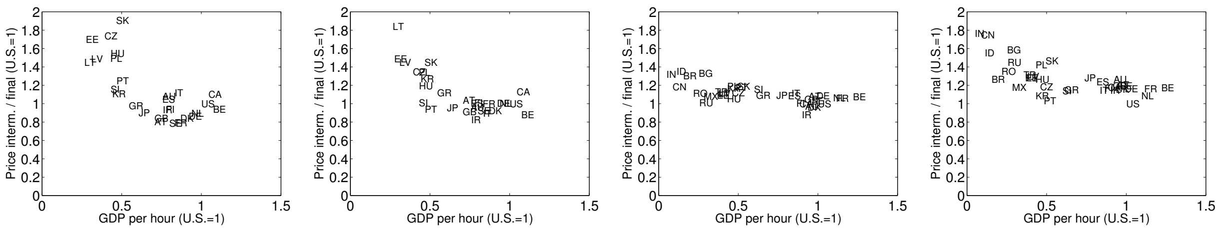
FIGURE 1. Relative price service/goods industries

Now consider relative prices across production stages. Figure (2) plots the relative price deflator of intermediate goods (services) to final goods (services) against GDP per hour. The methodologies behind the construction of these indices are different across the two samples so that the GGDC exhibits significantly more variation. Yet both samples suggest that in each of the two industries it is intermediates that are relatively expensive in poorer economies, $(p_{gm}/p_{gf})^{poor} > (p_{gm}/p_{gf})^{rich}$ and $(p_{sm}/p_{sf})^{poor} > (p_{sm}/p_{sf})^{rich}$. Poorer

[9]Here, as in the remainder, goods industries include industry labels A-F (agriculture, manufacturing, utilities, and construction) while services are labels G-P (private and public services).

[10]The coefficient of correlation (t-statistic) in the four panels is, respectively, 0.39 (3.90), 0.55 (6.46), 0.29 (6.37), and 0.27 (6.68).

countries appear to have a particular productivity problem in intermediate relative to final industries.[11]



(A) Goods, GGDC (B) Services, GGDC (C) Goods, WIOD (D) Services, WIOD

FIGURE 2. Relative price intermediate/final sectors

2.3. *Intermediate consumption shares and composition of inputs*

Next, I document the importance of intermediates across industries and countries. Figure (3) plots industry-specific intermediate shares (the value of the industry's intermediate consumption relative to its output) against hourly GDP. Two trends stand out. First, intermediate shares are weakly correlated with aggregate productivity. In the GGDC sample the correlation is slightly negative, and only for services it is statistically significant at standard thresholds. In the WIOD the correlation is slightly positive, and statistically insignificant.[12] Thus, by and large, intermediate intensities appear stable across countries. This fact has been previously pointed out elsewhere for the overall intermediate consumption ratio in the economy, for instance by Jones (2013).[13] The other feature emerging from Figure (3) is that the two broadly defined industries vary substantially in their requirement of intermediate inputs. The production of goods demands relatively more intermediate consumption than the production of services.[14]

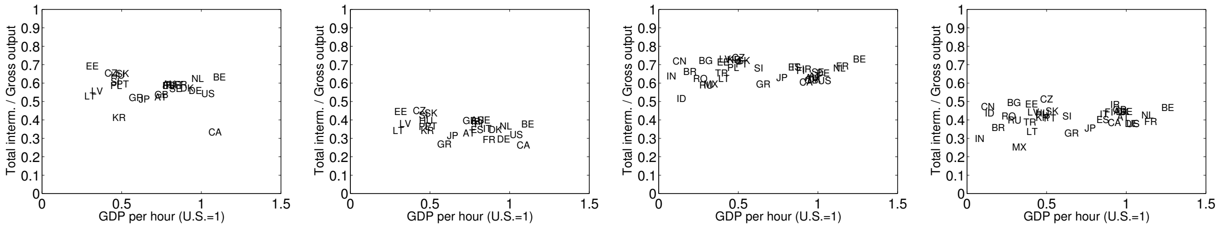
The composition of intermediate inputs, meanwhile, is not stable across countries. Figure (4) shows that in higher income countries, industries producing goods (services) tend

[11]The coefficient of correlation (t-statistic) in the four panels is, respectively, -0.96 (-5.96), -0.72 (-5.99), -0.21 (-6.00), and -0.36 (-5.91).

[12]The coefficient of correlation (t-statistic) in the four panels is, respectively, -0.07 (-1.32), -0.09 (-2.81), 0.01 (0.24), and 0.03 (1.07).

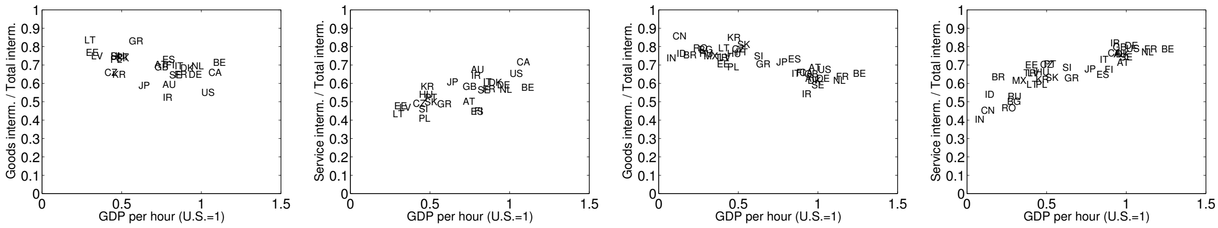
[13]That also chimes with time series data. The U.S., for instance, exhibits remarkably stable factor intensities for manufacturing and services from 1960 until today - see Moro (2012) and Herrendorf, Herrington and Valentinyi (2015).

[14]Differences in sectoral intermediate consumption shares have recently also been exploited in the literature on macroeconomic volatility (Moro 2012, Carvalho and Gabaix 2011, Moro 2015).



(A) Goods, GGDC (B) Services, GGDC (C) Goods, WIOD (D) Services, WIOD

FIGURE 3. Nominal intermediate consumption share



(A) Goods, GGDC (B) Services, GGDC (C) Goods, WIOD (D) Services, WIOD

FIGURE 4. Composition of nominal intermediate consumption

to spend relatively less (more) on intermediates deriving from their own sector. In lower income countries, goods industries are therefore more prominent as suppliers of intermediates.[15] To paraphrase, both rich and poor countries spend roughly an equal amount of σ_g (σ_s) cents on intermediates to produce one dollar of goods (service) output. Poor countries, however, will spend a larger *fraction* of σ_g and σ_s on intermediate goods rather than intermediate services. This could reflect an increase in outsourcing as economies develop, meaning that intermediate services are increasingly purchased from the market rather than produced in-house. However, more pronounced outsourcing would not be consistent with a declining share of goods intermediates and the resulting stable *total* intermediate share.

3. ECONOMIC ENVIRONMENT

3.1. *Model*

There are four sectors, populated each by a representative firm. A sector consists of an industry $i \in \{g, s\}$, denoting goods or services, and a production stage $j \in \{f, m\}$,

[15]The coefficient of correlation (t-statistic) in the four panels is, respectively, -0.16 (-3.57), 0.22 (5.08), -0.18 (-8.32), and 0.27 (11.1).

denoting final or intermediate production. The production function takes the form

$$y_{ij} = A_{ij} \left(\gamma_{gi}^{\frac{1}{\rho_i}} x_{gij}^{\frac{\rho_i - 1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sij}^{\frac{\rho_i - 1}{\rho_i}} \right)^{\frac{\sigma_i \rho_i}{\rho_i - 1}} l_{ij}^{1-\sigma_i}. \tag{1}$$

Output y_{ij} is produced using labor l_{ij} as well as a composite of intermediate goods x_{gij} and intermediate services x_{sij}. The parameter $\sigma_i \in (0,1)$ is the composite intermediate good factor share, $\rho_i > 0$ the elasticity of substitution between the two intermediate inputs and $\gamma_{gi}, \gamma_{si} \in (0,1)$ their relative intensities, with $\gamma_{gi} + \gamma_{si} = 1$. Total factor productivity (TFP) is represented by $A_{ij} > 0$.[16] All markets are competitive so the firm chooses its production factors to maximize profits $p_{ij} y_{ij} - p_{gm} x_{gij} - p_{sm} x_{sij} - w l_{ij}$ where p_{ij} is the price of output, p_{gm} and p_{sm} are, respectively, the prices of intermediates, and w denotes the wage.

The household maximizes utility

$$u(c_g, c_s) = \left(\omega_g^{\frac{1}{\rho}} c_g^{\frac{\rho - 1}{\rho}} + \omega_s^{\frac{1}{\rho}} c_s^{\frac{\rho - 1}{\rho}} \right)^{\frac{\rho}{\rho - 1}} \tag{2}$$

over the consumption of final goods and services c_g and c_s with an elasticity of substitution $\rho > 0$ and weights $\omega_g, \omega_s \in (0,1)$, $\omega_g + \omega_s = 1$. The household disposes of one unit of labor so that its budget constraint is $p_{gf} c_g + p_{sf} c_s \leq w$. This utility function implies that sectoral structural transformation is driven by relative price changes as proposed by Ngai and Pissarides (2007).[17] Note that preferences are introduced in order to close the model. The actual identification of TFP terms, however, will be independent of the preference specification.

Final and intermediate market clearing is given by

$$c_i = y_{if}, \;\; \forall i \in \{g, s\}, \tag{3}$$

$$x_{igf} + x_{isf} + x_{igm} + x_{ism} = y_{im}, \;\; \forall i \in \{g, s\}. \tag{4}$$

The larbor market clears according to

$$l_{gf} + l_{sf} + l_{gm} + l_{sm} = 1. \tag{5}$$

[16] In many papers TFP is the residual after accounting for capital and labor. Here, the term TFP has another connotation.

[17] Herrendorf, Rogerson and Valentinyi (2013) find that structural transformation in final expenditure shares in U.S. times series is better approximated by non-homothetic Stone-Geary preferences. I nonetheless choose the above utility specification because there is a clear cross-country correlation between the relative final price of goods to services and final expenditure shares. Herrendorf et al. (2013), using a different three-sector decomposition of consumption commodities only, do not find such a correlation over time in the U.S.

3.2. *Discussion*

At this point several clarifications are in order. The first concerns the breakup into two industries. As argued in the previous section, there are grounds to believe that along the dimensions of interest here - intermediate input intensity and relative productivity - there is a clear-cut distinction between industries producing goods and those producing services. The Cobb-Douglas specification between composite intermediate inputs and labor is chosen in light of the stable intermediate factor shares across countries presented in Figure (3). The relative mix of industry-specific intermediate demand is allowed to vary systematically with relative price changes, consistent with the discussed evidence in Figure (4). I interpret A as factor-neutral efficiency or the Solow residual. I thus follow Jones (2011) and the multi-factor analysis in the EU KLEMS data, which implicitly assume that efficiency is embedded in intermediate goods as well as in labor.

Second, while all parameters are industry-specific, the parametrization is identical across production stages j with the exception of the sector-specific TFP term. Empirically, most industries produce both final and intermediate goods, and many identical goods are sold both for final and intermediate consumption. While there is no clear-cut classification of final versus intermediate producers, it is possible to tease out differences in TFP between them by comparing relative final and intermediate prices for any given industry. We can think of the underlying differences as stemming from variations in the intra-industry composition between industries producing mostly final as opposed to mostly intermediate goods (say, cars versus steel).[18] Alternatively, we can also think of the TFP differences across production stages as reflecting institutional frictions (e.g. in market structure or contractual arrangements) that vary the efficiency at which identical physical goods are produced in response to destination.[19]

Apart from intermediates there is only one additional production factor, raw labour. We could in principle include other factors such as physical capital and land as well as express labor in term of human capital. We abstain from that for reasons of analytical tractability so as to focus on two endogenous production factors, intermediate goods and services. The present framework allows for a clear identification of the interplay between intermediate

[18]The Appendix breaks down sub-industries according to their importance as final and intermediate suppliers. The variations are sizeable.

[19]The GGDC data allows for that because it explicitly reports the price of intermediates (and indirectly that of final output) across countries. The exercise based on WIOD deflators will not capture such an effect because intermediate prices are constructed simply by weighting over sub-industries.

demand and supply on the one hand, and relative as well as aggregate productivity on the other. It comes without much loss of generality compared to a framework with additional production factors in exogenous aggregate supply because potentially distinct factor intensities across sectors can simply be subsumed in the sectoral TFP terms.[20]

A final aspect to point out is the absence of international trade. Following comparative advantage, economies are likely to circumvent the production of specific goods or services by importing them. Since the present framework does not allow for that we need to interpret the sectoral TFP terms more broadly. Say, for example, that an economy is identified as having particularly high intermediate goods prices. That is indicative of the economy having low productivity in sector gm, potentially because of its low technological efficiency. In addition, as shown formally in Hsieh and Klenow (2007), it can also reflect factors such as high trade frictions associated with imports, poor substitutability between imported and home-produced intermediate goods, or low productivity in the tradable component of goods and services produced in other sectors which are used to cover the required imports. Whichever of these factors applies, the crucial point is that the economy is constrained by relatively low productivity in sector gm. The present exercise identifies relatively unproductive sectors and characterizes their aggregate impact. A finer analysis including international trade flows would certainly add quantitative precision, yet at the cost of blurring the simple qualitative and quantitative message conveyed here.

4. Theoretical implications

The equilibrium leads to a straightforward characterization, summarized in the Appendix. This section studies comparative statics resulting from movements in the efficiency parameters A on prices and productivity. To highlight the effects I will - when convenient - consider one or both of the following restrictions.

Assumption 1. *Industry neutral development:* $A_{gf} \propto A_{sf}$ *and* $A_{gm} \propto A_{sm}$.

Assumption 2. *Production state neutral development:* $A_{gf} \propto A_{gm}$ *and* $A_{sf} \propto A_{sm}$.

Under the first scenario economies do not differ in relative industry-specific TFP while they may differ in relative TFP across production stages. Under the second scenario

[20] One could wonder whether relatively expensive intermediates in poor countries simply reflect the same industries that produce capital goods, which are known to be expensive in poorer countries following e.g. Hsieh and Klenow (2007). The Appendix reveals that such industries do not have larger weighting in intermediate versus final supply.

economies differ in terms of relative industry-specific TFP, but there is no interesting distinction between final and intermediate producers. To be clear, these are not statements about the data. They are employed to highlight the equilibrium, and they ultimately represent testable hypotheses.

4.1. *Expenditure shares*

By construction the nominal intermediate consumption shares in the two industries are constant across economies (σ_g and σ_s, respectively). The nominal composition of intermediate consumption is given by the following expressions.

$$G_{gg} \equiv \frac{p_{gm}(x_{ggf} + x_{ggm})}{p_{gm}(x_{ggf} + x_{ggm}) + p_{sm}(x_{sgf} + x_{sgm})} = \frac{\gamma_{gg}}{\gamma_{gg} + (1 - \gamma_{gg})\left(p_{sm}/p_{gm}\right)^{1-\rho_g}} \in (0,1)$$

denotes the nominal own-supply share in the goods industry (i.e. the intermediate consumption expenditure share on goods intermediates by the goods industry). Analogously,

$$G_{ss} \equiv \frac{p_{sm}(x_{ssf} + x_{ssm})}{p_{gm}(x_{gsf} + x_{gsm}) + p_{sm}(x_{ssf} + x_{ssm})} = \frac{\gamma_{ss}}{\gamma_{ss} + (1 - \gamma_{ss})\left(p_{sm}/p_{gm}\right)^{\rho_s-1}} \in (0,1)$$

is the nominal own-supply share in the service industry. Finally, let

$$O_g \equiv \frac{p_{gf}c_g}{p_{gf}c_g + p_{sf}c_s} = \frac{\omega_g}{\omega_g + (1 - \omega_g)\left(p_{sf}/p_{gf}\right)^{1-\rho}} \in (0,1)$$

denote the expenditure share on final goods.

Following Figure (1), as economies converge in income the price of services relative goods tends to rise, both across intermediate (p_{sm}/p_{gm}) and final sectors (p_{sf}/p_{gf}). It is well known that the final expenditure share on goods O_g typically falls with development, suggesting gross complementarity in final sectors ($\rho < 1$). What is less well known is that intermediate goods and services must also be gross complements in both industries ($\rho_g, \rho_s < 1$) to match the declining own-supply share in goods industries G_{gg} and the rising own-supply share in services G_{ss} presented in Figure (4).

4.2. *Relative prices and relative productivity*

The two price ratios across production stages are

$$\frac{p_{im}}{p_{if}} = \frac{A_{if}}{A_{im}}, \ \forall i \in \{s, g\}. \tag{6}$$

The structure imposed on the production functions implies that the ratio of TFPs across production stages can be read directly from the respective price ratio. Figure (2) suggests that poorer countries are relatively inefficient at producing intermediates in both goods and service industries.

The third price ratio, between final goods and services, is implicit from

$$\frac{p_{sf}}{p_{gf}} = \frac{(1-\sigma_g)\,\sigma_g^{\frac{\sigma_g}{1-\sigma_g}}}{(1-\sigma_s)\,\sigma_s^{\frac{\sigma_s}{1-\sigma_s}}} \frac{A_{gf}A_{gm}^{\frac{\sigma_g}{1-\sigma_g}}}{A_{sf}A_{sm}^{\frac{\sigma_s}{1-\sigma_s}}} \frac{\left(\gamma_{ss}+(1-\gamma_{ss})\left(\frac{A_{sf}}{A_{gf}}\frac{A_{gm}}{A_{sm}}\frac{p_{sf}}{p_{gf}}\right)^{\rho_s-1}\right)^{\frac{\sigma_s}{(1-\sigma_s)(1-\rho_s)}}}{\left(\gamma_{gg}+(1-\gamma_{gg})\left(\frac{A_{sf}}{A_{gf}}\frac{A_{gm}}{A_{sm}}\frac{p_{sf}}{p_{gf}}\right)^{1-\rho_g}\right)^{\frac{\sigma_g}{(1-\sigma_g)(1-\rho_g)}}}. \tag{7}$$

The price ratio p_{sf}/p_{gf} fully describes the relative relative productivity between final industries since

$$\frac{y_{gf}/l_{gf}}{y_{sf}/l_{sf}} = \frac{1-\sigma_s}{1-\sigma_g}\frac{p_{sf}}{p_{gf}}. \tag{8}$$

A similar expression obtains for intermediates:

$$\frac{y_{gm}/l_{gm}}{y_{sm}/l_{sm}} = \frac{1-\sigma_s}{1-\sigma_g}\frac{p_{sm}}{p_{gm}}.$$

If, say, final (intermediate) services relative to goods were twice more expensive in country R compared to country P, then country R compared to country P would indeed be twice more productive in final (intermediate) goods relative to services. This is not to say, however, that these price ratios are also relevant measures of relative *efficiency levels* across industries. The final price ratio reacts to efficiency changes according to

$$\begin{aligned}\frac{\mathrm{d}(p_{sf}/p_{gf})}{p_{sf}/p_{gf}} =& \frac{\mathrm{d}A_{gf}}{A_{gf}} + \frac{\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)(1-G_{ss})}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\frac{\mathrm{d}A_{gm}}{A_{gm}} \\ &+ \frac{\mathrm{d}A_{sf}}{A_{sf}} + \frac{\sigma_g(1-\sigma_s)(1-G_{gg})-\sigma_s(1-\sigma_g)G_{ss}}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\frac{\mathrm{d}A_{sm}}{A_{sm}}.\end{aligned}$$

As for the elasticity of the intermediate price ratio, it is independent of A_{gf} and A_{sf},

$$\begin{aligned}\frac{\mathrm{d}(p_{sm}/p_{gm})}{p_{sm}/p_{gm}} =& \frac{1-\sigma_s}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\frac{\mathrm{d}A_{gm}}{A_{gm}} \\ &- \frac{1-\sigma_g}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\frac{\mathrm{d}A_{sm}}{A_{sm}}.\end{aligned}$$

To obtain a sharper characterization it is convenient to consider outcomes under industry neutrality ($\mathrm{d}A_f/A_f \equiv \mathrm{d}A_{gf}/A_{gf} = \mathrm{d}A_{sf}/A_{sf}$ and $\mathrm{d}A_m/A_m \equiv \mathrm{d}A_{gm}/A_{gm} = \mathrm{d}A_{sm}/A_{sm}$) and/or production stage neutrality ($\mathrm{d}A_g/A_g \equiv \mathrm{d}A_{gf}/A_{gf} = \mathrm{d}A_{gm}/A_{gm}$ and $\mathrm{d}A_s/A_s \equiv \mathrm{d}A_{sf}/A_{sf} = \mathrm{d}A_{sm}/A_{sm}$).

Proposition 1. *Assume the economy experiences positive differential changes in all sectoral TFP levels. This results in an increase in the price ratios p_{sf}/p_{gf} and p_{sm}/p_{gm}, and therefore a decrease the labor productivity of services relative to goods at both final* *and intermediate production stages if and only if: (i) $\sigma_g > \sigma_s$ under Assumption (1); (ii) $(dA_g/A_g)/(dA_s/A_s) > (1-\sigma_s)/(1-\sigma_g)$ under Assumption (2); (iii) $\sigma_g > \sigma_s$ under Assumptions (1) and (2).*

Proof. Appendix. □

Figure (3) indicates that goods industries have a higher intermediate factor share than services ($\sigma_g > \sigma_s$). The stylized fact that the relative price of final service expenditures p_{sf}/p_{gf} increases as a country catches up in development hence does not imply that convergence is necessarily accompanied by higher TFP growth in the goods industry compared to services. Because the production of goods is more sensitive to the cost of intermediates, (industry-neutral) increases in efficiency are likely to magnify the relative labor productivity of goods vis-à-vis services.[21] It need not be that poorer countries are particularly inefficient at producing goods relative to services, whether at the final or the intermediate stage. Indeed, the second part of Proposition 1 states that converging countries could have faster growth in services ($\mathrm{d}A_g/A_g < \mathrm{d}A_s/A_s$) compared to goods yet still experience an increase in the ratios p_{sf}/p_{gf} and p_{sm}/p_{gm} as long as the growth differential in services is smaller than $(1-\sigma_s)/(1-\sigma_g)$. Even if rich countries were relatively more efficient at producing services than goods, goods may still turn out to be relatively cheaper in these countries due to the demand side of the input-output relationship. Not taking this relationship into account by focusing only on the relative price of final goods may hence lead to a flawed identification of 'problem industries' in poor countries.

4.3. *Aggregate productivity*

A second objective of this paper is to determine the elasticity of GDP per worker to changes in efficiency. Let real GDP equal the representative agent's indirect utility, $Y = (p_{gf}y_{gf}+p_{sf}y_{sf})/P$, i.e. final expenditure (value-added) divided by the ideal price deflator $P \equiv \left(\omega_g p_{gf}^{1-\rho} + \omega_s p_{sf}^{1-\rho}\right)^{\frac{1}{1-\rho}}$. From here we have $\mathrm{d}Y/Y = \eta_{gf}(\mathrm{d}A_{gf}/A_{gf}) + \eta_{sf}(\mathrm{d}A_{sf}/A_{sf}) +$

[21]This is analogous to international trade theories in the tradition of Hekscher and Ohlin where poor countries are considered relatively unproductive in capital intensity industries and where capital endowments are fixed. Here, intermediate inputs are not fixed, but their supply is relatively less abundant than labor in poor countries because their aggregate production is lower.

$\eta_{gm}(\mathrm{d}A_{gm}/A_{gm}) + \eta_{sm}(\mathrm{d}A_{sm}/A_{sm})$ with elasticities $\eta_{gf} = O_g$, $\eta_{sf} = 1 - O_g$,

$$\eta_{gm} = \frac{\sigma_s(1-G_{ss})[1-(1-\sigma_g)O_g] + \sigma_g(1-\sigma_s)G_{gg}O_g}{1-\sigma_g\sigma_s - \sigma_g(1-\sigma_s)G_{gg} - \sigma_s(1-\sigma_g)G_{ss}},$$
$$\eta_{sm} = \frac{\sigma_g(1-G_{gg})[1-(1-\sigma_s)(1-O_g)] + \sigma_s(1-\sigma_g)G_{ss}(1-O_g)}{1-\sigma_g\sigma_s - \sigma_g(1-\sigma_s)G_{gg} - \sigma_s(1-\sigma_g)G_{ss}}.$$

This is again more conveniently analyzed by imposing either industry or production stage neutrality. Under Assumption (1) $\eta_f \equiv \eta_{gf} + \eta_{sf} = 1$ and $\eta_m \equiv \eta_{gm} + \eta_{sm}$; under Assumption (2) $\eta_g \equiv \eta_{gf} + \eta_{gm}$ and $\eta_s \equiv \eta_{sf} + \eta_{sm}$; and under Assumptions (1) and (2) $\eta \equiv \eta_{gf} + \eta_{sf} + \eta_{gm} + \eta_{sm}$. These elasticities are functions of relative expenditure shares, implying that countries at different stages of development are likely to have distinct elasticities of GDP to TFP, as summarized in the following Proposition.

Proposition 2. *Consider two economies R and P such that $O_g^R < O_g^P$, $G_{gg}^R < G_{gg}^P$, and $G_{ss}^R > G_{ss}^P$. Then the GDP elasticities in the two economies compare as follows. Under Assumption (1) $\eta_g^P > \eta_g^R$, $\eta_s^P < \eta_s^R$; under Assumption (2) $\eta_f^P = \eta_f^R$ while $\eta_m^P > \eta_m^R$ if and only if $\sigma_g > \sigma_s$; under Assumptions (1) and (2) $\eta^P > \eta^R$ if and only if $\sigma_g > \sigma_s$.*

Proof. Appendix. □

As discussed above, poorer economies typically have relatively high expenditure shares on goods in final and intermediate consumption (high O_g and G_{gg}, low G_{ss}). Production stage neutral TFP growth in the goods sector therefore affects GDP relatively strongly in such economies, while TFP changes in the service sector have a comparatively smaller impact. Industry neutral TFP changes in final sectors have a unitary multiplier in all economies, while those in the intermediate sectors are comparatively stronger in poorer economies for the empirically relevant case of $\sigma_g > \sigma_s$. This follows from the fact that intermediate sector efficiency is disproportionately valuable in economies that have high expenditure shares on intermediate-intensive goods, both in final as well as in intermediate consumption. As a result, structural transformation implies that intermediates carry an increasingly lower weight as the economy develops, and GDP becomes less responsive to aggregate (production stage and industry neutral) TFP. Baumol's 'cost disease' is therefore accentuated by the composition of intermediate inputs. Moro (2015) makes the same point, but here the argument is augmented by secular variations in G_{gg} and G_{ss}, in addition to those of O_g.

5. Quantitative Analysis

In this section I calibrate the model and infer county-specific implied efficiency levels A. I then analyze the patterns exhibited by the TFP levels, test the importance of the assumptions used in the inference, and compute elasticities to TFP growth. All quantifications are done separately on the GGDC and WIOD samples.

5.1. *Inference of TFP*

5.1.1. *Calibration of joint parameters*

The model parameters are chosen by minimizing the data-model distance in key observables over the total number of countries in each sample. The calibration proceeds in three separate steps. First, σ_g and σ_s, respectively, are pinned down by the average industry-specific intermediate input share across all countries. Second, the parameters governing the composition of intermediate inputs are backed out by rewriting the expressions G_{gg} and G_{ss} to

$$\log \frac{p_{gm}\left(x_{ggf}+x_{ggm}\right)}{p_{sm}\left(x_{sgf}+x_{sgm}\right)} = \log \frac{\gamma_{gg}}{1-\gamma_{gg}} + \left(\rho_g - 1\right) \log \frac{p_{sm}}{p_{gm}} \tag{9}$$

and

$$\log \frac{p_{gm}\left(x_{gsf}+x_{gsm}\right)}{p_{sm}\left(x_{ssf}+x_{ssm}\right)} = \log \frac{1-\gamma_{ss}}{\gamma_{ss}} + \left(\rho_s - 1\right) \log \frac{p_{sm}}{p_{gm}}. \tag{10}$$

The parameters are computed, for each industry, via cross-country OLS regressions of the ratio of intermediate expenditure on goods to services on the relative price of intermediate services to goods. This completes the calibration of the parameters that are necessary to retrieve TFP levels. For the purpose of running counterfactuals, however, it is necessary to close the model via the first order condition implicit in O_g. That can be rewritten to

$$\log \frac{p_{gf} c_g}{p_{sf} c_s} = \log \frac{\omega_g}{1-\omega_g} + (\rho - 1) \log \frac{p_{sf}}{p_{gf}}. \tag{11}$$

An OLS regression of the ratio of final expenditure of goods to services on the relative price of final services to goods gives the required parameters.

Parameter	GGDC 1997	WIOD 2005	Target
σ_g	0.571	0.663	Avg. interm. share, goods ind.
σ_s	0.363	0.415	Avg. interm. share, service ind.
ρ_g	0.104	0.100	Elast. of interm. composition, goods ind.
γ_{gg}	0.672	0.691	Avg. interm. composition, goods ind.
ρ_s	0.207	0.100	Elast. of interm. composition, service ind.
γ_{ss}	0.573	0.704	Avg. interm. composition, service ind.
ρ	0.801	0.100	Price elast. of final composition
ω	0.251	0.363	Avg. final composition

Table 1. Benchmark calibration

The resulting values are reported in Table (1). The intermediate intensities are lower in the GGDC data since it nets out intra-industry deliveries at the lowest level of aggregation. In both datasets, however, the goods industry reveals a substantially higher intermediate input share. Both datasets also imply strong complementarity between intermediate goods and services in each industry as well as between final goods and services. In fact, the WIOD suggests negative elasticities of substitution in all three regressions.[22] As these have no economic interpretation I set them all to low positive values ($\rho_g = \rho_s = \rho = 0.1$) and recompute the relative weights under that restriction. In the counteractual exercise further below it becomes clear that the calibration of TFP levels is actually quite insensitive to the exact value of ρ_g and ρ_s.

5.1.2. *Country-specific moments*

Next I use key country-specific moments to pin down the four efficiency levels. The first two moments are p_{gm}/p_{gf} and p_{sm}/p_{sf} that directly fix each country's relative efficiency levels across production stages. The price ratio of final services to goods p_{sf}/p_{gf} then sets the relative efficiency levels across final industries.[23] The fourth identifying equation is each country's aggregate GDP per hour worked. For this, model GDP is evaluated as $= y_{gf} + (p_{sf}/p_{gf})^{U.S.} y_{sf}$, namely based on a constant U.S. relative final price ratio.[24] The fifth chosen moment is the value added ratio between goods and services, a measure of allocation of resources across sectors. The robustness of the proposed method depends on how well the model fares on non-targeted moments, which is summarized in the Appendix.

5.2. *Results*

5.2.1. *Sectoral TFP and aggregate productivity*

Figure (5) presents the inferred efficiency levels for the two samples. Each series is normalized to the U.S. and plotted against GDP per hour. Not surprisingly, high-income countries tend to be more efficient in all sectors. The statistical correlation between sectoral TFP and hourly GDP is measured by ε via the regression $\log A = \alpha + \varepsilon \log GDP/H$, and reported in the first line of Table (2).

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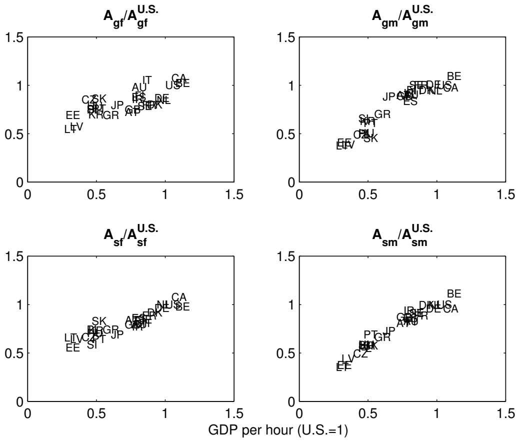
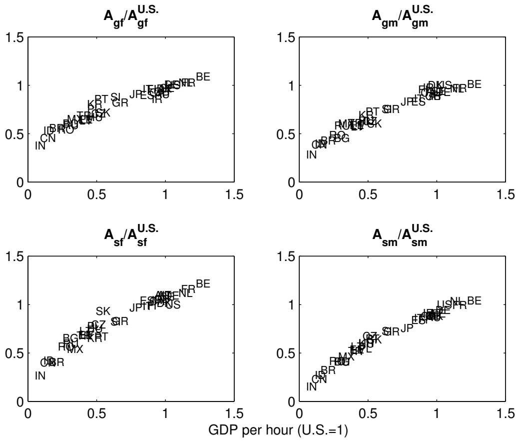
[22]Namely, $\rho_g = -0.72$, $\rho_s = -1.01$, and $\rho = -0.68$, and weights $\gamma_{gg} = 0.66$, $\gamma_{ss} = 0.73$, and $\omega_g = 0.31$.

[23]The price of the final good p_f is the numéraire. All price ratios are normalized to the U.S.

[24]In the data, cross-country GDP is of course evaluated in international prices. As is well known these are close to U.S. prices because of that country's weight in the construction of international prices.



(A) GGDC 1997



(B) WIOD 2005

FIGURE 5. Implied efficiency levels

For the GGDC sample cross-country TFP gaps tend to be substantially larger in intermediate than final sectors, in the sense that ε is higher for intermediates. Meanwhile, the elasticity for goods and services is of similar magnitude. The gap between rich and poor countries is a bit larger in final services relative to final goods, and a bit smaller in intermediate services relative to intermediate goods. As for the WIOD sample, the TFP elasticities are quite aligned across sectors. They confirm, however, that poorer countries are particularly inefficient at producing intermediates. Comparing across industries, it is also noteworthy that poorer countries now appear to have disproportionately low TFP levels in *service* rather than goods sectors.

		GGDC 1997				WIOD 2005			
Scenarios		A_{gf}	A_{sf}	A_{gm}	A_{sm}	A_{gf}	A_{sf}	A_{gm}	A_{sm}
Benchmark	ε	0.31	0.37	0.80	0.75	0.32	0.45	0.41	0.58
	$1^{st}/5^{th}$ quintile	0.73	0.69	0.44	0.46	0.55	0.43	0.46	0.34
$A_{gf}/A_{gm}=1$, $A_{sf}/A_{sm}=1$	ε	0.57	0.52	0.57	0.52	0.39	0.50	0.39	0.50
	$1^{st}/5^{th}$ quintile	0.56	0.59	0.56	0.59	0.48	0.39	0.48	0.39
$\sigma_g=\sigma_s$	ε	0.51	0.25	1.00	0.63	0.48	0.34	0.57	0.47
	$1^{st}/5^{th}$ quintile	0.60	0.77	0.36	0.52	0.41	0.53	0.35	0.41
$\rho_g=\rho_s=0.5$	ε	0.31	0.37	0.80	0.75	0.32	0.45	0.41	0.58
	$1^{st}/5^{th}$ quintile	0.73	0.69	0.45	0.47	0.55	0.43	0.47	0.34
$\rho_g=\rho_s\to 1$	ε	0.31	0.36	0.80	0.74	0.32	0.44	0.41	0.58
	$1^{st}/5^{th}$ quintile	0.73	0.69	0.44	0.47	0.55	0.44	0.47	0.34

TABLE 2. Elasticity of efficiency to empirical GDP

Why are there such differences across the samples? Apart from different sample countries and years, there are two main reasons. The GGDC provides a direct measure of intermediate relative to final output prices, and the resulting cross-country gap turns out to be larger. It hence accentuates the cross-country gap in the ratios A_{gm}/A_{gf} and A_{sm}/A_{sf}. At the same time, the definition of intermediate inputs is more restrictive in the GGDC sample, which lowers the intermediate input shares and in particular the input share difference between goods and services. Relative industry price variations across countries are then driven more by relative TFP than by the multipliers. The opposite is true in the WIOD sample, where poor countries consequently turn out to have relatively high TFP in goods rather than services.

Finally, the second line of Table (2) puts these findings into perspective by reporting the predicted TFP ratio between the average first and the average fifth quintile of countries as ordered by GDP per hour. The corresponding hourly GDP ratios are 0.36 in the GGDC and 0.15 in the WIOD.[25] The TFP gaps are remarkably smaller than the GDP gaps. In the WIOD, for instance, an almost 7-fold factor difference in GDP results from TFP gaps that range between factors of less than 2 (0.55) to 3 (0.34).

5.2.2. *Industry and production stage neutrality*

Another question of interest is the correlation of sectoral TFP levels to understand whether there exists a pattern. More precisely, is development biased toward a particular industry or production stage?

Under industry neutrality, Assumption (1), I estimate the elasticities ϕ_f and ϕ_m in the respective series $A_{sf} = A_{gf}^{\phi_f}$ and $A_{sm} = A_{gm}^{\phi_m}$. If ϕ_f and ϕ_m turn out to be significantly different from unity I reject industry neutrality. For this I regress $\log A_{sj}/A_{gj}$ on $\log A_{gj}$ separately for each production stage $j = \{f, m\}$, yielding $\hat{\phi}_j = 1 + \hat{\beta}_j$. If there is industry bias, the next question is whether it is independent of the production stage. For this I pool the series $\log A_{sj}/A_{gj}$ across both stages ($\log A_{s\cdot}/A_{g\cdot}$) and regress it on a single series $A_{g\cdot}$ featuring the relevant counterpart (A_{gf} or A_{gm}). The resulting parameter $\hat{\phi} = 1 + \hat{\beta}$

[25]In the GGDC sample the least productive countries are (from bottom up): Lithuania, Estonia, Latvia, the Czech Republic, Poland, and Slovenia, with an average productivity of 0.35 relative to the U.S. The most productive are (from top down): Belgium, Canada, the U.S., the Netherlands, Germany, and Denmark, averaging 0.97 relative to the U.S. In the WIOD the corresponding quintiles are India, China, Indonesia, Brazil, Romania, Bulgaria, and Russia (0.16) as well as Belgium, France, the Netherlands, the U.S., Germany, Sweden, and Austria (1.05).

estimates the industry bias in the pooled sample and allows a structural break test for $\phi = \phi_f = \phi_m$.

Turning to production stage neutrality the test is analogous. Under Assumption (2) I test whether the specifications $A_{gm} = A_{gf}^{\mu_g}$ and $A_{sm} = A_{sf}^{\mu_s}$ yield production stage neutrality, $\mu_g = \mu_s = 1$. If not, I ask whether the bias is independent of industry, i.e. whether it allows a representation such that $\mu = \mu_g = \mu_s$.

	GGDC 1997			WIOD 2005		
	$\log A_{sf}/A_{gf}$	$\log A_{sm}/A_{gm}$	$\log A_{s\cdot}/A_{g\cdot}$	$\log A_{sf}/A_{gf}$	$\log A_{sm}/A_{gm}$	$\log A_{s\cdot}/A_{g\cdot}$
constant$_m$	✓		✓	✓		✓
constant$_f$		✓	✓		✓	✓
$\log A_{gf}$	−0.317**			0.297***		
	(0.146)			(0.080)		
$\log A_{gm}$		−0.123**			0.375***	
		(0.052)			(0.053)	
$\log A_g$			−0.159***			0.345***
			(0.054)			(0.045)
	$\log A_{gm}/A_{gf}$	$\log A_{sm}/A_{sf}$	$\log A_{\cdot m}/A_{\cdot f}$	$\log A_{gm}/A_{gf}$	$\log A_{sm}/A_{sf}$	$\log A_{\cdot m}/A_{\cdot f}$
constant$_g$	✓		✓	✓		✓
constant$_s$		✓	✓		✓	✓
$\log A_{gf}$	0.403			0.220***		
	(0.287)			(0.047)		
$\log A_{sf}$		0.534***			0.246***	
		(0.192)			(0.045)	
$\log A_f$			0.471***			0.237***
			(0.163)			(0.031)
Obs.	27	27	54	36	36	72

Note: Statistical significance at 0.1, 0.05, 0.01 is indicated by *, **, ***, respectively.

TABLE 3. Test for industry neutral and production stage neutral development

In the upper half of Table (3), industry neutrality is firmly rejected in both datasets, but with contrary signs. In the GGDC sample development is biased towards goods industries while the opposite occurs in the WIOD sample. In fact, these relationships appear independent of production stages as the F-statistics for structural break make it difficult to reject the pooled representations (0.528 and 0.206, respectively). I conclude that $\phi = 1 - 0.16 = 0.84$ in the GGDC (mild bias towards goods industries) and $\phi = 1 + 0.35 = 1.35$ in the WIOD (substantial bias towards service industries).

Moving on to development stage neutrality in the lower half of Table (3), it is strongly rejected in all but one constellation. Quantitatively it also appears independent of industry as the F-statistics (0.040 in each sample) indicate a superb fit for the restricted representation. The resulting elasticities $\mu = 1 + 0.47 = 1.47$ (GGDC) and $\mu = 1 + 0.24 = 1.24$ (WIOD) confirm that development is biased towards intermediate sectors.

5.2.3. *Counterfactual inference*

Our development accounting framework is motivated by the recognition that (i) the production of final and intermediate goods commands different efficiency levels across countries; (ii) goods and services differ in intermediate intensity; (iii) the composition of intermediates differs across countries. The lower part of Table (2) presents the consequence on TFP measurement of closing down any of these variations one at a time.

To address the first point I recompute efficiency levels $A_{gf} = A_{gm}$ and $A_{sf} = A_{sm}$ by ignoring production stage-specificity and setting $p_{gm}/p_{gf} = p_{sm}/p_{sf} = 1$ in each country. In both samples the cross-country TFP variation compared to the benchmark increases in final sectors (higher elasticity with respect to hourly GDP) while it declines in intermediate sectors. Also, the difference in the cross-country gap between services and goods either narrows (WIOD) or even reverses (GGDC in the case of the final sector). In order to account for more expensive final goods relative to services in poor countries the model forces these countries to have relatively low TFP levels in goods producing industries. Note, however, that in the WIOD sample it is still the service industries that appear relatively inefficient in poor countries. Distinct intermediate intensities across industries are hence sufficient to deliver a *positive* correlation between $p_{g\cdot}/p_{s\cdot}$ and $A_{g\cdot}/A_{s\cdot}$.

A confirmation of that follows in the next exercise. Here TFP levels are inferred as in the benchmark, with the sole difference of equalizing intermediate intensity across industries. For illustration, the intensity is set to averages across sectors, namely $\sigma_g = \sigma_s = (0.570 + 0.363)/2 = 0.456$ in the GGDC and analogously to 0.534 in the WIOD. In both samples poor countries now appear significantly less efficient in the production of goods rather than services. Failing to account for differential intermediate input intensities across industries creates not only a quantitative but a qualitative bias in the diagnosis of cross-country relative sectoral TFP gaps. Also, notice that not only in the GGDC, but also in the WIOD poor countries now appear to have particularly low TFP in goods industries. This suggests that the original WIOD finding of relatively low *service* TFP levels in poor countries results from the larger cross-industry difference in intermediate intensity in that sample compared to the GGDC.

The third question concerns the importance of variations in the nominal composition of intermediate inputs. This is especially important given that the estimation of equations (9) and (10) is likely to be biased due to confounding demand and supply effects. For this I recompute the TFP levels for alternative elasticities of substitution, namely for a medium value ($\rho_g = \rho_s = 0.5$) and unity ($\rho_g = \rho_s \to 1$). Surprisingly, in both samples the variation in the inferred efficiency levels is almost - though not exactly - identical to that in the benchmark.[26] This can be seen from the last four lines of Table (2). The Appendix subsection 7.3 describes why the large variation in relative prices of intermediate services to goods across countries ultimately has little impact on the inference of sectoral TFP.

5.2.4. *TFP growth, GDP and relative prices*

The benchmark accounting exercise establishes that poor countries have relatively low TFP levels in intermediate vis-à-vis final sectors. In addition, the WIOD (though not the GGDC) sample also suggests that they are characterized by relatively low TFP levels in service vis-à-vis goods sectors. This is not to say, however, that growth in the relatively inefficient sectors is most conducive to aggregate GDP growth. In the following exercise I compute country-specific elasticities of GDP - measured again at fixed U.S. prices - with respect to sectoral TFP. The considered changes are, one at a time, in final sectors ($A_{\cdot f}$), intermediate sectors ($A_{\cdot m}$), goods sectors ($A_{g\cdot}$), service sectors ($A_{s\cdot}$), and all sectors combined ($A_{\cdot\cdot}$). This being an equilibrium response, the model is closed using the household optimality condition (17). For completeness, I also compute the elasticity of the relative final price, the measure or relative productivity across final sectors.[27]

Elasticities (%)		GGDC 1997 $A_{\cdot f}$	$A_{\cdot m}$	$A_{g\cdot}$	$A_{s\cdot}$	$A_{\cdot\cdot}$	WIOD 2005 $A_{\cdot f}$	$A_{\cdot m}$	$A_{g\cdot}$	$A_{s\cdot}$	$A_{\cdot\cdot}$
GDP ($y_{gf} + y_{sf}$)	10^{th}	1.00	0.80	0.72	1.09	1.81	1.00	1.21	1.18	1.02	2.23
	50^{th}	1.00	0.80	0.68	1.11	1.80	1.00	1.17	1.08	1.08	2.18
	90^{th}	1.00	0.79	0.67	1.12	1.80	1.00	1.12	0.96	1.15	2.13
Final price (p_{sf}/p_{gf})	10^{th}	0.00	0.46	1.43	−0.95	0.46	0.00	0.72	1.69	−0.96	0.72
	50^{th}	0.00	0.45	1.39	−0.93	0.45	0.00	0.70	1.67	−0.95	0.70
	90^{th}	0.00	0.45	1.38	−0.92	0.45	0.00	0.69	1.64	−0.93	0.69

TABLE 4. Predicted elasticities of GDP and the relative final price to TFP

Table (4) summarizes the predicted elasticities for three relevant groups of countries ordered by empirical GDP per hour - poor, median, and rich.[28] The elasticity to final sector TFP is exactly unity. Contrast that to the intermediate TFP elasticity. According

[26] I also experimented with different combinations of ρ_g and ρ_s, yielding very similar results.

[27] Baseline GDP is therefore not exactly identical to its empirical counterpart, but it is close. The projection of actual GDP on baseline equilibrium GDP predicts a ratio of 0.36 (0.16) between the 10^{th} versus the 90^{th} percentile in the GGDC (WIOD), almost exactly equal to the empirical ratio 0.36 (0.15).

[28] Each experiment gives country-specific elasticities e. The predicted elasticity for particular groups is obtained from the projection of the regression $\log e = \alpha + \beta \log GDP$.

to the GGDC sample countries benefit relatively less from intermediate TFP while in the WIOD data - due to higher intermediate intensities - the gain is relatively larger. This is especially true for the poorer countries in the sample. Comparing across industries, growth in service industry TFP is more beneficial than that in goods industries except for the poorest countries in the WIOD sample. As for the increase in aggregate TFP across the board, the GDP multiplier is substantial in the WIOD sample. Finally, notice that a neutral TFP increase leads to a substantial rise in the price of services relative to goods.

6. Concluding remarks

Which are the sectors that are particularly inefficient in poor countries? This paper finds that they are sectors producing intermediate as opposed to final output. Poor countries reveal enormous catch-up potential in sectors producing intermediates. Also, it shows that it is not clearly goods relatively to service sectors that are particularly inefficient. Instead, the relatively inefficient sector in the cross-industry comparison depends on the data sample and the definition of intermediate inputs. Finally, given the high elasticity of GDP to TFP, the aggregate productivity gains from minor increases in TFP are sizeable.

There is interest in directing more research in combining the leverage effects discussed here with an explicit theory of efficiency in intermediate input procurement. It is also worthwhile looking into the exact reasons why TFP in intermediate sectors is relatively low in poorer countries. The analysis of TFP gaps between goods and services across countries, meanwhile, may be of more limited interest. The fact that poor countries have particularly low measured labor productivity in goods as opposed to service industries may simply boil down to cross-industry differences in intermediate intensity in conjunction with low intermediate TFP.

7. Appendix

7.1. *Data*

The following describes the data sources and the construction of all the employed series.

7.1.1. *GGDC 1997*

Almost all of the country-specific series calculated here are based on the GGDC dataset for the year 1997.[29] The sub-industries $k \in G$ comprising goods are: Agriculture, hunting, forestry and fishing (AtB), Mining and quarrying (C), Food products, beverages and tobacco (15t16), Textiles, textile products, leather and footwear (17t19), Wood and products of wood and cork (20), Pulp, paper, paper products, printing and publishing (21t22), Coke, refined petroleum products and nuclear fuel (23), Chemicals and chemical products (24), Rubber and plastics products (25), Other non-metallic mineral products (26), Basic metals and fabricated metal products (27t28), Machinery, nec (29), Electrical and optical equipment (30t33), Transport equipment (34t35), Manufacturing nec; recycling (36t37), Electricity, gas and water supply (E), Construction (F). The sub-industries $k \in S$ comprising services are: Trade (G), Hotels and restaurants (H), Post and telecommunications (64), Transport and storage (60t63), Financial intermediation (J), Real estate activities (70), Renting of machinery & equipment and other business activities (71t74), Public administration and defence; compulsory social security (L), Education (M), Health and social work (N), Other community, social and personal services (O), Private households with employed persons (P).

The series for intermediate good prices is based on the intermediate input price deflator, PPP_IIS for services and the weighted average between the price of energy inputs (PPP_IIE) and material inputs (PPP_IIM) for goods. Each series is a geometric mean over all the two-digit sub-industries in the dataset, the weights being the supply shares (IIS and IIE+IIM, respectively) to each sub-industry. The intermediate input price is hence simply the mean over the prices that all the sub-industries k in the economy (pertaining both to goods G and service S industries) spend on that particular intermediate input.

$$p_{sm} = \prod_{l \in G,S} PPP\_IIS_k^{\frac{IIS_k}{\sum_{l \in G,S} IIS_k}};$$

$$p_{gm} = \prod_{k \in G,S} \left(PPP\_IIE_k^{\frac{IIE_k}{\sum_{k \in G,S}(IIE_k + IIM_k)}} \times PPP\_IIM_k^{\frac{IIM_k}{\sum_{k \in G,S}(IIE_k + IIM_k)}} \right).$$

Next, the series for the final price is computed via the intermediary construction of the aggregate output price p_o, based on the output deflator (PPP_SO). The output price for goods and services is assumed to be a geometric mean of the sub-industries with gross

[29] See http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database-1997-benchmark.

output as expenditure share weights (SO).

$$p_{os} = \prod_{k\in S} PPP\_SO_k^{\frac{SO_k}{\sum_{k\in S} SO_k}} \text{ and } p_{og} = \prod_{k\in G} PPP\_SO_k^{\frac{SO_k}{\sum_{k\in G} SO_k}}.$$

From here, I compute the final price p_f assuming that the output price is approximated by a geometric mean between the final and intermediate price. The weight of the intermediate price is simply the value of aggregate intermediate consumption on the good or service (the aggregate value of IIS and $IIE{+}IIM$, respectively) as a share of aggregate output (SO). The final price is hence implicitly defined from

$$p_{os} = p_{sm}^{\frac{\sum_{k\in G,S} IIS_k}{\sum_{k\in S} SO_k}} \times p_{sf}^{\frac{\sum_{k\in S} SO_k - \sum_{l\in G,S} IIS_k}{\sum_{k\in S} SO_k}},$$

$$p_{og} = p_{gm}^{\frac{\sum_{k\in G,S}(IIE_k+IIM_k)}{\sum_{k\in G} SO_k}} \times p_{gf}^{\frac{\sum_{k\in G} SO_k - \sum_{k\in G,S}(IIE_k+IIM_k)}{\sum_{k\in G} SO_k}},$$

This gives all the price ratios, which as a last step are normalized to 1 for the U.S.

Industry gross output is given by $p_{gf}y_{gf} + p_{gm}y_{gm} = \sum_{k\in G} SO_k$ and $p_{sf}y_{sf} + p_{sm}y_{sm} = \sum_{k\in S} SO_s$. Industry-specific intermediate consumption is $p_{gm}(x_{ggf}+x_{ggm}) = \sum_{k\in G}(IIE_k + IIM_k)$, $p_{sm}(x_{sgf} + x_{sgm}) = \sum_{k\in G} IIS_k$, $p_{gm}(x_{gsf} + x_{gsm}) = \sum_{k\in S}(IIE_k + IIM_k)$, and $p_{sm}(x_{ssf} + x_{ssm}) = \sum_{k\in S} IIS_k$. These yield the nominal ratios of intermediate intensity, intermediate composition, gross output, and value-added. The construction of the final expenditure ratio $(p_{gf}c_g)/(p_{sf}c_s)$, however, cannot be directly inferred and is based on the WIOD data (for the year 1997) as described further below.

GDP per hour equals the ratio between value added of total industries VA (TOT) and total hours worked $HOURS$ (TOT), divided by the total industry value added deflator PPP_VA (TOT). The fraction of hours worked in goods industries is constructed by adding hours worked in all sub-industries pertaining to goods and dividing by total hours worked.

7.1.2. *WIOD 2005*

The WIOD data report comprehensive and comparable use and supply tables.[30] We only make use of the National Input-Output tables and discard the international linkages that are additionally provided in that dataset.[31] The decomposition into goods and service industries is identical to that of the GGDC, and summarized in Table (5).

[30] Following the common practice I delete countries with less than one million inhabitants, which are Cyprus, Malta, and Luxembourg in both datasets. In addition, I do not consider Taiwan in the WIOD because of missing price data. The exclusion of these countries creates no substantial difference.

[31] Available at http://www.wiod.org/new_site/database/niots.htm.

The basic ingredient for the construction of relative prices are internationally comparable output deflators. These cover 35 sub-industries k and are built as a complement to the WIOD tables.[32] For each industry, the price of the intermediate (final) output is computed as a geometric mean of the underlying sub-industry output deflators ($labelledGO\_35Industry$). The country-specific weights are the supply shares of each sub-industry's sum of products that are delivered either for intermediate or final consumption. For each sub-industry I first compute the share of output that is delivered for intermediate as opposed to final consumption. Intermediate consumption is labelled $INTC$ in the use tables (USE_bas) of the WIOD. The final consumption share is the sum of Final consumption expenditure ($CONS$) and Gross capital formation (GCF). Exports are not considered because the data do not allow them to be categorized as serving intermediate or final consumption - the underlying assumption that the split follows the domestic use. For each subsector k we thus have

$$share_{mk} = \frac{INTC_k}{INTC_k + CONS_k + GCF_k} \text{ and } share_{fk} = \frac{CONS_k + GCF_k}{INTC_k + CONS_k + GCF_k}.$$

The actual weights are obtained by multiplying the above share by the sub-industry's gross output at basic prices (GO). The weights for each production stage $j = \{f, m\}$ are therefore

$$weight_{gjk} = \frac{share_{jk}GO_k}{\sum_{k \in G} share_{jk}GO_k}$$

for goods industries, and

$$weight_{sjk} = \frac{share_{jk}GO_k}{\sum_{k \in S} share_{jk}GO_k}$$

for service industries. Applying a geometric mean yields the resulting price for each production stage $j = \{f, m\}$:

$$p_{gj} = \prod_{k \in G} \left(GO\_35Industry_k^{weight_{gjk}} \right) \text{ and } p_{sj} = \prod_{k \in S} \left(GO\_35Industry_k^{weight_{sjk}} \right).$$

This allows for the construction of all the price ratios, which are finally normalized to 1 for the U.S.

Table (5) orders the sub-industries by the average weight (across all countries) in each industry-production stage pair. For information it also reports the average cross-country share of each sub-industries output delivered either in the form of intermediate or final use.

[32]The price data are obtained from http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database?lang=en.

Intermediate output				Final output			
Industry	Code	Weight	Share	Industry	Code	Weight	Share
Goods industries							
Basic & fabric. metal	27t28	13.0	89	Construction	F	29.9	75
Agr., forestry & fishing	AtB	8.3	64	Food, bever. & tobacco	15t16	15.6	67
Construction	F	8.0	25	Transport equipment	34t35	8.7	60
Utilities	E	7.8	68	Electr. & optical equip.	30t33	6.7	44
Electr. & optical equip.	30t33	7.7	56	Agr., forestry & fishing	AtB	6.6	36
Chemical products	24	7.5	69	Other machinery	29	6.3	60
Mining & quarrying	C	6.1	95	Utilities	E	4.8	32
Food, bever. & tobacco	15t16	5.9	33	Chemical products	24	4.0	31
Coke & refined petrol.	23	5.6	65	Coke & refined petrol.	23	3.7	35
Transport equipment	34t35	5.6	40	Textiles	17t18	3.7	59
Paper, printing & publ.	21t22	5.4	77	Other manufacturing	36t37	3.2	65
Rubber & plastics	25	3.8	88	Paper, printing & publ.	21t22	2.3	23
Non-metal. mineral prod.	26	3.8	89	Basic & fabric. metal	27t28	1.9	10
Wood products	20	3.6	92	Leather & footwear	19	0.8	72
Other machinery	29	3.4	40	Non-metal. mineral prod.	26	0.6	11
Textiles	17t18	2.8	41	Rubber & plastics	25	0.6	12
Other manufacturing	36t37	1.4	35	Mining & quarrying	C	0.4	5
Leather & footwear	19	0.4	28	Wood products	20	0.3	8
Service industries							
Business services	71t74	22.7	80	Government	L	15.1	95
Wholesale trade	51	12.6	56	Real estate	70	14.1	71
Financial services	J	11.5	64	Health	N	11.7	93
Land transport	60	9.0	63	Education	M	9.0	94
Retail trade	52	8.6	49	Wholesale trade	51	8.1	44
Real estate	70	7.0	29	Retail trade	52	6.9	51
Post & telecomm.	64	6.5	63	Other services	O	6.8	64
Transport services	63	5.6	73	Hotels & restaurants	H	6.3	77
Other services	O	4.9	36	Financial services	J	5.1	36
Motor veh. & fuel trade	50	3.2	50	Land transport	60	4.7	37
Hotels & restaurants	H	2.3	23	Business services	71t74	4.0	20
Water transport	61	2.1	75	Post & telecomm.	64	3.0	37
Air transport	62	1.2	58	Motor veh. & fuel trade	50	2.4	50
Health	N	1.1	7	Transport services	63	1.6	27
Government	L	1.0	5	Air transport	62	0.7	42
Education	M	0.7	6	Water transport	61	0.5	25
H-holds w/ empl. pers.	P	0.0	3	H-holds w/ empl. pers.	P	0.5	97

Table 5. Average weights and intermediate versus final supply shares per industry-production stage pair

Gross output of the goods (service industry) is the sum of total gross output (USE_bas, line GO) of categories AtB through to F (34t35 through to FISIM for services). Nominal intermediate consumption of goods (services) by the goods industry is computed as the the sum of intermediate consumption from the use table at basic prices (USE_bas) as well as net taxes ($NetTaxes$) from suppliers 1-45 (50-95) for sub-industries AtB through to F. For nominal intermediate consumption by the service industry the computation is analogous but summed over sub-industries 34t35 through to FISIM. These give the requirements for nominal ratios on intermediate intensity, intermediate composition, gross output, and value-added. As for the ratio of final expenditure $(p_{gf}c_g)/(p_{sf}c_s)$, the numerator (denominator) consists of the sum over Final consumption on Expenditure ($CONS$), Gross

Capital Formation (GCF) and Exports (EXP) of the use table at basic prices (USE_bas) as well as net taxes ($NetTaxes$) from suppliers 1-45 (50-95 for the denominator). These values (for the appropriate year) are also used for the GGDC 1997 calibration.

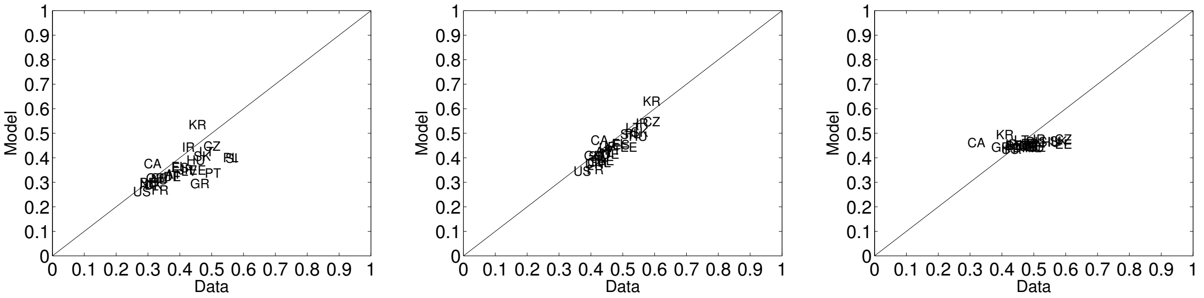
Aggregate productivity is obtained from two additional data sources. The numerator consists of GDP in international dollars from the Total Economy Database of The Conference Board, series EKS GDP.[33] Total hours worked are obtained from the WIOD Socio-Economic Accounts.[34] The series used is Total hours worked by persons engaged (H_EMP, TOT). For the fraction of hours worked in goods industries I sum the series Total hours worked by persons engaged (H_EMP), entries AtB through to F, and divide by the sum of total industries (TOT).

7.2. *Model-data match*

In addition to efficiency levels the model delivers a number of non-targeted moments that can be compared to the data. I consider three moments of interest, summarized in Figures (6) and (7) for each sample. A perfect match coincides with the 45 degrees line. The first panel depicts the share of hours worked in the goods industry, l_g. In both the GGDC and the WIOD samples the match to the data is pretty good. In both cases, however, the model does tend to underestimate hours worked in the goods industry for countries that have a large fraction of hours in that industry. Turning to the second panel, the model does a good job in matching the share of gross output represented by the goods industry, $(p_{gf}y_{gf} + p_{gm}y_{gm})/(p_{gf}y_{gf} + p_{gm}y_{gm} + p_{sf}y_{sf} + p_{sm}y_{sm})$. In the model that statistic equals $[1 + (1 - \sigma_g)/(1 - \sigma_s)\delta^{-1}]^{-1}$ where δ is the targeted value-added ratio of goods versus services. The model's overlap with the data indicates that by and large countries that feature a higher (lower) intermediate share in goods than imposed by the model (σ_g) also are likely to have a higher (lower) intermediate share in services than posited by σ_s. This is why the model does worse on matching the share of intermediates in gross output, portrayed in the third panel. The model's outcome delivers values comprised strictly between σ_s and σ_g while some countries lie on or beyond that boundary. Note, however, that only a couple of countries depart significantly from the prediction, while the rest is firmly anchored around an intermediate share of about 0.45 or 0.55, depending on the sample.

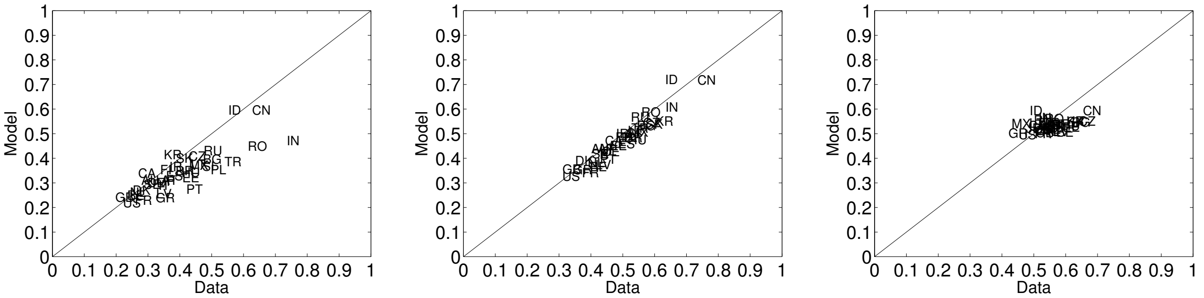
[33] The data are available at http://www.conference-board.org/data/economydatabase/

[34] The data are available at http://www.wiod.org/new_site/database/seas.htm



(A) Hours share, goods industry (B) Output share, goods industry (C) Output share, intermediates

Figure 6. Model outcome versus data, GGDC 1997



(A) Hours share, goods industry (B) Output share, goods industry (C) Output share, intermediates

Figure 7. Model outcome versus data, WIOD 2005

7.3. *Sensitivity to elasticities of substitution*

Here I describe how the inference of the TFP terms depends on the elasticity of substitution between inputs. Substituting for optimality conditions, sectoral production can be rewritten to

$$y_{gf} = A_{gf}^{\frac{1}{1-\sigma_g}} B_g l_{gf},$$

$$y_{sf} = A_{sf}^{\frac{1}{1-\sigma_g}} B_s l_{sf},$$

$$y_{gm} = A_{gm}^{\frac{1}{1-\sigma_g}} \left(\frac{p_{gm}}{p_{gf}}\right)^{\frac{\sigma_g}{1-\sigma_g}} B_g l_{gm},$$

$$y_{sm} = A_{sm}^{\frac{1}{1-\sigma_s}} \left(\frac{p_{sm}}{p_{sf}}\right)^{\frac{\sigma_s}{1-\sigma_s}} B_s l_{sm},$$

where

$$B_g \equiv \sigma_g^{\frac{\sigma_g}{1-\sigma_g}} \left(\gamma_{gg} + (1-\gamma_{gg}) \left(\frac{p_{sm}}{p_{gm}}\right)^{1-\rho_g}\right)^{\frac{\sigma_g}{(1-\sigma_g)(\rho_g-1)}}$$

and

$$B_g \equiv \frac{\left(\frac{p_{gm}}{p_{gf}}\right)^{\frac{\sigma_g}{1-\sigma_g}}}{\left(\frac{p_{sm}}{p_{sf}}\right)^{\frac{\sigma_s}{1-\sigma_s}}} \sigma_s^{\frac{\sigma_s}{1-\sigma_s}} \left(\gamma_{ss} + (1-\gamma_{ss}) \left(\frac{p_{sm}}{p_{gm}}\right)^{\rho_s - 1}\right)^{\frac{\sigma_s}{(1-\sigma_s)(\rho_s-1)}}.$$

Given data on prices, and holding y and l constant, the TFP terms therefore depend on ρ_g and ρ_s primarily through the terms B_g and B_s. It turns out that these are not highly sensitive to ρ_g and ρ_s, despite large cross-country variations in p_{sm}/p_{gm}.[35] Comparing each country's B_g and B_s at $\rho_g = \rho_s = 0.5$ to their value at benchmark where $\rho_g = 0.104$ and $\rho_s = 0.207$ ($\rho_g = \rho_s = 0.1$), the maximum absolute variation in the GGDC (WIOD) sample is 1.8% and 0.7% (1.6% and 0.7%). The maximum absolute variation at $\rho_g = \rho_s \rightarrow 1$ relative to the benchmark in the GGDC (WIOD) sample is 4.2% and 1.9% (3.7% and 1.5%). These variations, however, do not translate directly into TFP differences because of the endogenous responses in y and l to match the calibration targets. As a result, the inferred sectoral TFP levels are only marginally affected by the elasticity of substitution between intermediate inputs.

7.4. *Solutions*

7.4.1. *Solution of the theoretical model*

The firms' first order conditions with respect to l_{ij} give, $\forall i \in \{g, s\}$ and $\forall j \in \{f, m\}$,

$$\frac{w}{p_{ij}} \frac{l_{ij}}{y_{ij}} = 1 - \sigma_i. \tag{12}$$

The first order conditions with respect to x_{gij} and x_{sij} are, $\forall i \in \{g, s\}$ and $\forall j \in \{f, m\}$,

$$\frac{p_{gm}}{p_{ij}} = A_{ij}\sigma_i \left(\gamma_{gi}^{\frac{1}{\rho_i}} x_{gij}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sij}^{\frac{\rho_i-1}{\rho_i}}\right)^{\frac{1-(1-\sigma_i)\rho_i}{\rho_i-1}} \gamma_{gi}^{\frac{1}{\rho_i}} x_{gij}^{\frac{-1}{\rho_i}} l_{ij}^{1-\sigma_i}$$

and

$$\frac{p_{sm}}{p_{ij}} = A_{ij}\sigma_i \left(\gamma_{gi}^{\frac{1}{\rho_i}} x_{gij}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sij}^{\frac{\rho_i-1}{\rho_i}}\right)^{\frac{1-(1-\sigma_i)\rho_i}{\rho_i-1}} \gamma_{si}^{\frac{1}{\rho_i}} x_{sij}^{\frac{-1}{\rho_i}} l_{ij}^{1-\sigma_i}.$$

These can be rewritten to, $\forall i \in \{g, s\}$ and $\forall j \in \{f, m\}$,

$$x_{gij} = \left(\frac{p_{ij}}{p_{gm}} A_{ij}\sigma_i\right)^{\frac{1}{1-\sigma_i}} \left(\gamma_{gi} + \gamma_{si}\left(\frac{p_{sm}}{p_{gm}}\right)^{1-\rho_i}\right)^{\frac{(1-\sigma_i)\rho_i - 1}{(1-\rho_i)(1-\sigma_i)}} \gamma_{gi} l_{ij}, \tag{13}$$

[35] The ratio between the highest and lowest p_{sm}/p_{gm} is 2.07 in the GGDC and 1.79 in the WIOD sample.

$$x_{sij} = \left(\frac{p_{ij}}{p_{sm}} A_{ij}\sigma_i\right)^{\frac{1}{1-\sigma_i}} \left(\gamma_{si} + \gamma_{gi}\left(\frac{p_{sm}}{p_{gm}}\right)^{\rho_i - 1}\right)^{\frac{(1-\sigma_i)\rho_i - 1}{(1-\rho_i)(1-\sigma_i)}} \gamma_{si} l_{ij}. \tag{14}$$

Combining these two equations with (12) and (1) gives, $\forall j \in \{f, m\}$,

$$\frac{w}{p_{ig}} = \left(\frac{p_{gj}}{p_{gm}}\right)^{\frac{\sigma_g}{1-\sigma_g}} A_{gj}^{\frac{1}{1-\sigma_g}} \sigma_g^{\frac{\sigma_g}{1-\sigma_g}} (1-\sigma_g)\left(\gamma_{gg} + (1-\gamma_{sg})\left(\frac{p_{sm}}{p_{gm}}\right)^{1-\rho_g}\right)^{\frac{\sigma_g}{(1-\sigma_g)(\rho_g - 1)}} \tag{15}$$

and

$$\frac{w}{p_{is}} = \left(\frac{p_{sj}}{p_{sm}}\right)^{\frac{\sigma_s}{1-\sigma_s}} A_{sj}^{\frac{1}{1-\sigma_s}} \sigma_s^{\frac{\sigma_s}{1-\sigma_s}} (1-\sigma_s)\left(\gamma_{ss} + (1-\gamma_{ss})\left(\frac{p_{sm}}{p_{gm}}\right)^{\rho_s - 1}\right)^{\frac{\sigma_s}{(1-\sigma_s)(\rho_s - 1)}}. \tag{16}$$

The household's maximization problem implies

$$\frac{p_{sf}}{p_{gf}} = \frac{u_{c_s}}{u_{c_g}} = \left(\frac{(1-\omega_g)}{\omega_g}\frac{c_g}{c_s}\right)^{\frac{1}{\rho}}. \tag{17}$$

Equations (13)-(17), coupled with the production functions (1) and the clearing conditions (3)-(5) fully characterize the equilibrium.

7.4.2. *Additional expressions*

Combining (15) and (16) yields the relative price ratio across production stages (6). Dividing (15) by (16) and using (6) then gives the relative final price ratio (7). The industry-specific nominal own-supply shares of composite intermediate consumption G_{gg} and G_{ss} are obtained using (6) and (13)-(14). The final expenditure share on goods O_g obtains directly from (17).

To compute real GDP note that as $w = Y^n$, $Y = Y^n/P = w/\left(\omega_g p_{gf}^{1-\rho} + \omega_s p_{sf}^{1-\rho}\right)^{\frac{1}{1-\rho}}$. Progressively substituting in (12) for any pair i and j, (1) and finally (13) and (14) obtains the indirect utility function:

$$Y = \frac{(1-\sigma_g)\,\sigma_g^{\frac{\sigma_g}{1-\sigma_g}} A_{gf} A_{gm}^{\frac{\sigma_g}{1-\sigma_g}} \left(\gamma_{gg} + (1-\gamma_{gg})\left(\frac{A_{sf}}{A_{gf}}\frac{A_{gm}}{A_{sm}}\frac{p_{sf}}{p_{gf}}\right)^{1-\rho_g}\right)^{\frac{\sigma_g}{(\rho_g - 1)(1-\sigma_g)}}}{\left(\omega_g + (1-\omega_g)\left(\frac{p_{sf}}{p_{gf}}\right)^{1-\rho}\right)^{\frac{1}{1-\rho}}}. \tag{18}$$

7.4.3. *Elasticities*

To compute the final price elasticity, use (7) to obtain

$$\begin{aligned}\log\frac{p_{sf}}{p_{gf}} &= \log A_{gf}-\log A_{sf}+\frac{\sigma_g}{1-\sigma_g}\log A_{gm}-\frac{\sigma_s}{1-\sigma_s}\log A_{sm}\\&+\frac{\sigma_g}{(\rho_g-1)(1-\sigma_g)}\log\left(\gamma_{gg}+(1-\gamma_{gg})\left(\frac{A_{sf}}{A_{gf}}\frac{A_{gm}}{A_{sm}}\frac{p_{sf}}{p_{gf}}\right)^{1-\rho_g}\right)\\&-\frac{\sigma_s}{(\rho_s-1)(1-\sigma_s)}\log\left(\left(\frac{A_{sf}}{A_{gf}}\frac{A_{gm}}{A_{sm}}\frac{p_{sf}}{p_{gf}}\right)^{\rho_s-1}(1-\gamma_{ss})+\gamma_{ss}\right).\end{aligned}$$

Full differentiation gives

$$\begin{aligned}\Lambda\frac{\mathrm{d}\left(p_{sf}/p_{gf}\right)}{p_{sf}/p_{gf}} &= \left(1+\tfrac{\sigma_g}{1-\sigma_g}(1-G_{gg})+\tfrac{\sigma_s}{1-\sigma_s}(1-G_{ss})\right)\left(\tfrac{\mathrm{d}A_{gf}}{A_{gf}}-\tfrac{\mathrm{d}A_{sf}}{A_{sf}}\right)\\&+\left(\tfrac{\sigma_g}{1-\sigma_g}-\tfrac{\sigma_g}{1-\sigma_g}(1-G_{gg})-\tfrac{\sigma_s}{1-\sigma_s}(1-G_{ss})\right)\tfrac{\mathrm{d}A_{gm}}{A_{gm}}\\&-\left(\tfrac{\sigma_s}{1-\sigma_s}-\tfrac{\sigma_g}{1-\sigma_g}(1-G_{gg})-\tfrac{\sigma_s}{1-\sigma_s}(1-G_{ss})\right)\tfrac{\mathrm{d}A_{sm}}{A_{sm}}\end{aligned}$$

where

$$\Lambda\equiv 1+\frac{\sigma_g}{1-\sigma_g}(1-G_{gg})+\frac{\sigma_s}{1-\sigma_s}(1-G_{ss}).$$

Further simplification yields

$$\begin{aligned}\frac{\mathrm{d}\left(p_{sf}/p_{gf}\right)}{p_{sf}/p_{gf}} &= \tfrac{\mathrm{d}A_{gf}}{A_{gf}}+\left(\tfrac{\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)(1-G_{ss})}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{gm}}{A_{gm}}\\&-\tfrac{\mathrm{d}A_{sf}}{A_{sf}}+\left(\tfrac{\sigma_g(1-\sigma_s)(1-G_{gg})-\sigma_s(1-\sigma_g)G_{ss}}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{sm}}{A_{sm}}\end{aligned}\tag{19}$$

Since $p_{sm}/p_{gm}=(A_{sf}/A_{gf})(A_{gm}/A_{sm})(p_{sf}/p_{gs})$ that also yields

$$\begin{aligned}\frac{\mathrm{d}\left(p_{sm}/p_{gm}\right)}{p_{sm}/p_{gm}} &= \left(\tfrac{1-\sigma_s}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{gm}}{A_{gm}}\\&-\left(\tfrac{1-\sigma_g}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{sm}}{A_{sm}}\end{aligned}\tag{20}$$

Finally, to compute the elasticity with respect to Y, take logs of (18), use $p_{sm}/p_{gm}=(A_{sf}/A_{gf})(A_{gm}/A_{sm})(p_{sf}/p_{gs})$, and differentiate fully to obtain

$$\frac{\mathrm{d}Y}{Y}=\frac{\mathrm{d}A_{gf}}{A_{gf}}+\frac{\sigma_g}{1-\sigma_g}\frac{\mathrm{d}A_{gm}}{A_{gm}}-\frac{\sigma_g(1-G_{gg})}{1-\sigma_g}\frac{\mathrm{d}\left(p_{sm}/p_{gm}\right)}{p_{sm}/p_{gm}}-(1-O_g)\frac{\mathrm{d}\left(p_{sf}/p_{gf}\right)}{p_{sf}/p_{gf}}.$$

Replacing the values from (19) and (20) obtains

$$\begin{aligned}\frac{\mathrm{d}Y}{Y} &= O_g\tfrac{\mathrm{d}A_{gf}}{A_{gf}}+\left(\tfrac{\sigma_s(1-G_{ss})[1-(1-\sigma_g)O_g]+\sigma_g(1-\sigma_s)G_{gg}O_g}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{gm}}{A_{gm}}\\&+(1-O_g)\tfrac{\mathrm{d}A_{sf}}{A_{sf}}+\left(\tfrac{\sigma_g(1-G_{gg})[1-(1-\sigma_s)(1-O_g)]+\sigma_s(1-\sigma_g)G_{ss}(1-O_g)}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}\right)\tfrac{\mathrm{d}A_{sm}}{A_{sm}}.\end{aligned}\tag{21}$$

7.4.4. *Proof of Proposition 1*

The proof is immediate by finding the condition such that $\frac{\mathrm{d}(p_{sf}/p_{gf})}{p_{sf}/p_{gf}} > 0$ in (19) and $\frac{\mathrm{d}(p_{sm}/p_{gm})}{p_{sm}/p_{gm}} > 0$ in (20), and by imposing either (i) industry neutrality ($\mathrm{d}A_{gf}/A_{gf} = \mathrm{d}A_{sf}/A_{sf}$ and $\mathrm{d}A_{gm}/A_{gm} = \mathrm{d}A_{sm}/A_{sm}$), (ii) production stage neutrality ($\mathrm{d}A_{gf}/A_{gf} = \mathrm{d}A_{gm}/A_{gm}$ and $\mathrm{d}A_{sf}/A_{sf} = \mathrm{d}A_{sm}/A_{sm}$), (iii) or both. The statements also apply to relative productivity across industries since relative prices and relative productivities are proportional from (12).

7.4.5. *Proof of Proposition 2*

The elasticities are as follows. Under Assumption (1), $\eta_f = 1$ and

$$\eta_m = \frac{\sigma_g O_g + \sigma_s(1-O_g) + \sigma_g\sigma_s(1-G_{gg}-G_{ss})}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}.$$

Under Assumption (2)

$$\eta_g = \frac{(1-\sigma_s)O_g + \sigma_s(1-G_{ss})}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}},$$

$$\eta_s = \frac{(1-\sigma_g)(1-O_g) + \sigma_g(1-G_{gg})}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}.$$

Combining the two gives Assumptions gives

$$\eta = \frac{1+\sigma_g O_g + \sigma_s(1-O_g) - \sigma_g G_{gg} - \sigma_s G_{ss}}{1-\sigma_g\sigma_s-\sigma_g(1-\sigma_s)G_{gg}-\sigma_s(1-\sigma_g)G_{ss}}.$$

Consider first η_g. Since $\frac{\partial\eta_g(G_{gg},G_{ss},O_g)}{\partial G_{gg}} > 0$, $\frac{\partial\eta_g(G_{gg},G_{ss},O_g)}{\partial G_{ss}} < 0$, and $\frac{\partial\eta_g(G_{gg},G_{ss},O_g)}{\partial O_g} > 0$, this proves that $\eta_g^R < \eta_g^P$. Similarly, $\frac{\partial\eta_s(G_{gg},G_{ss},O_g)}{\partial G_{gg}} < 0$, $\frac{\partial\eta_s(G_{gg},G_{ss},O_g)}{\partial G_{ss}} > 0$, and $\frac{\partial\eta_s(G_{gg},G_{ss},O_g)}{\partial O_g} < 0$, so $\eta_s^R > \eta_s^P$. For the final sector, $\eta_f^R = \eta_f^P = 1$. Next, if and only if $\sigma_g > \sigma_s$ we have that $\frac{\partial\eta_m(G_{gg},G_{ss},O_g)}{\partial G_{gg}} > 0$, $\frac{\partial\eta_m(G_{gg},G_{ss},O_g)}{\partial G_{ss}} < 0$, and $\frac{\partial\eta_m(G_{gg},G_{ss},O_g)}{\partial O_g} > 0$, and therefore $\eta_m^R < \eta_m^P$. The same argument is then true for the overall elasticity η.

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